Remote Sensing of Turbulence

Larry B. Cornman

National Center for Atmospheric Research

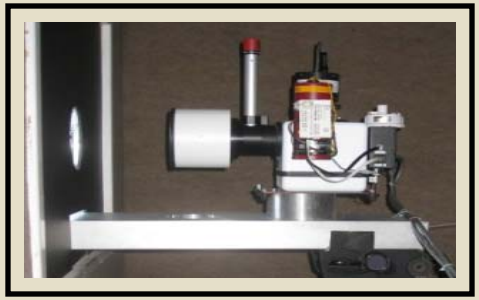
NCAR

Remote Sensing of Turbulence: An Inverse Problem

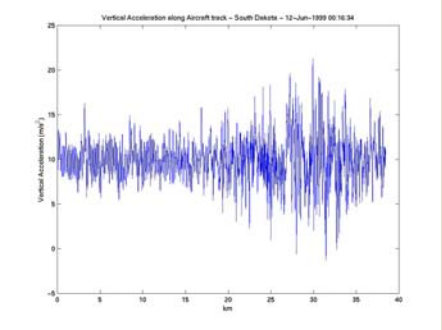
"*Sensor as turbulence filter*"

Input signal
(turbulence)

Sensor



Output signal
(sensor measurements)

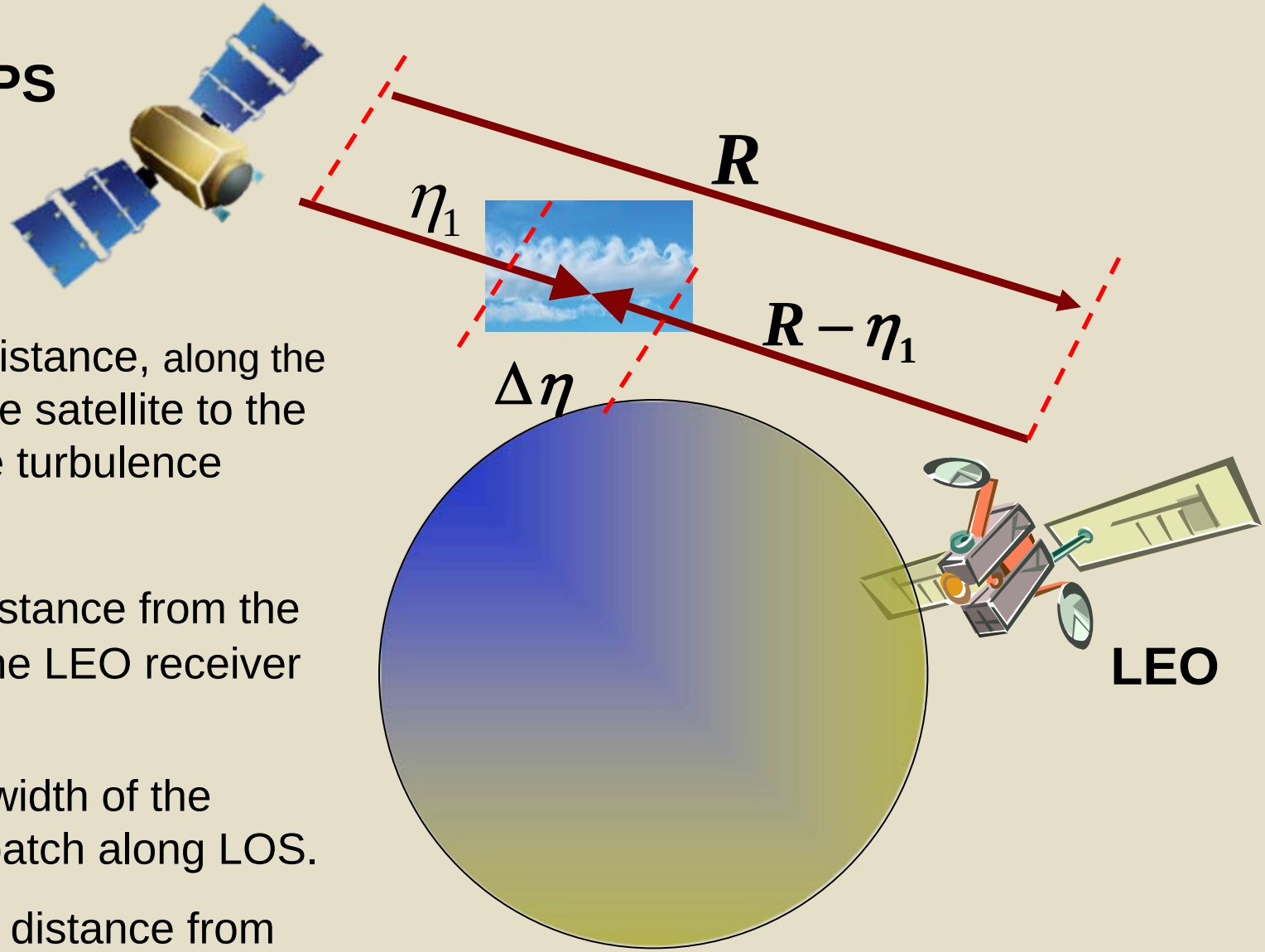


<u>But, we want to go backwards</u>:

Given statistics of the sensor output – and a model of how the sensor "filters" the turbulence – estimate the statistics of the turbulence.

NCAR

GPS-LEO Measurements of Turbulence



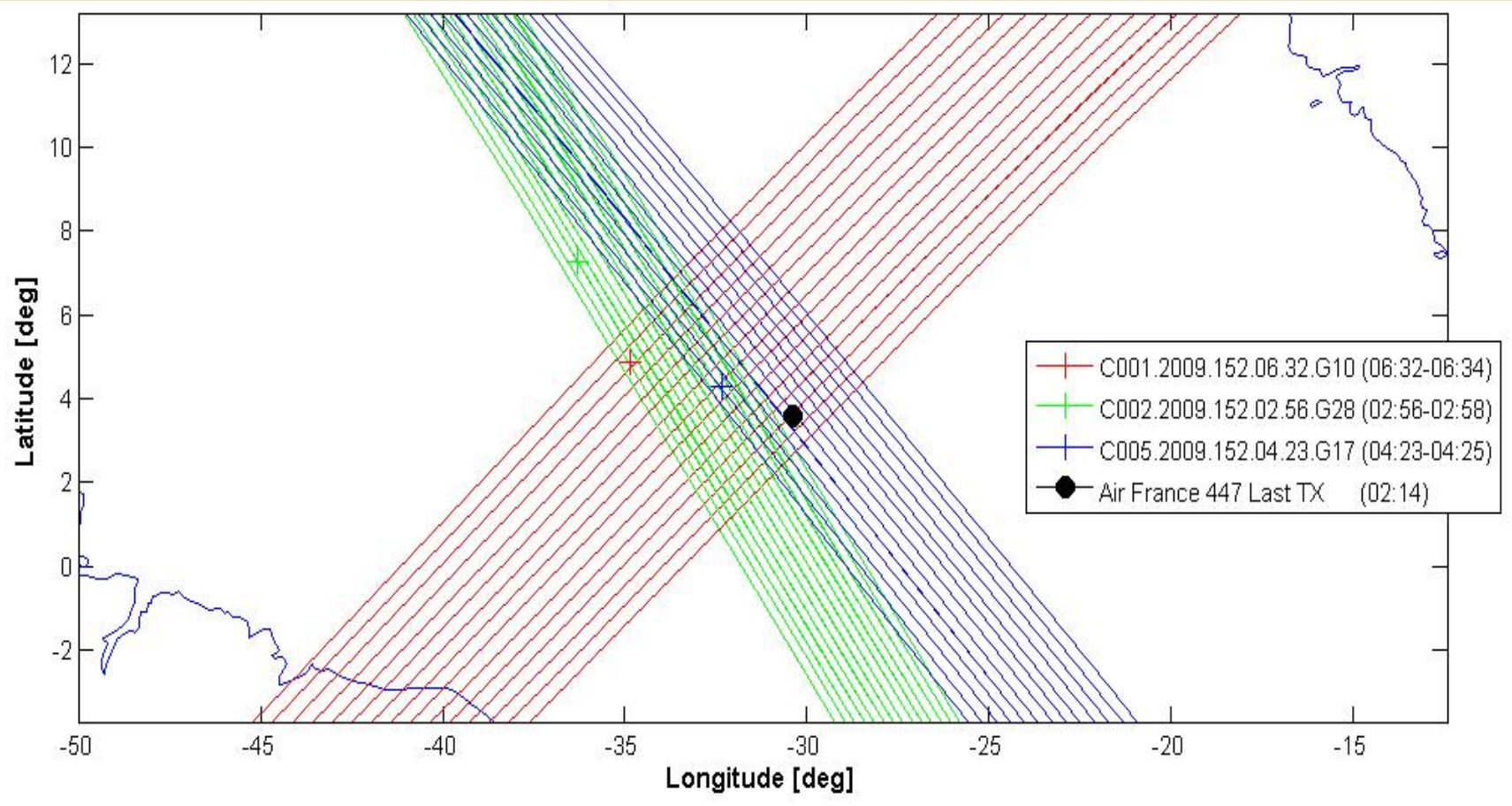
η_1 is the distance, along the LOS, from the satellite to the center of the turbulence patch.

R is the distance from the satellite to the LEO receiver along LOS.

$\Delta\eta$ is the width of the turbulence patch along LOS.

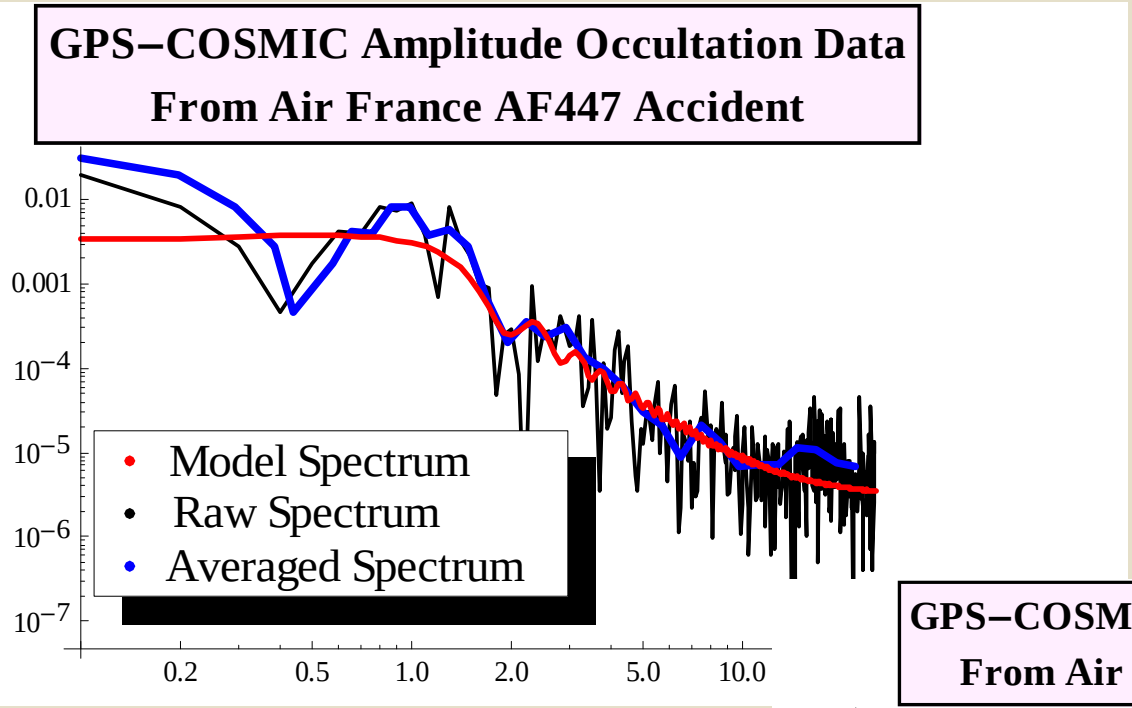
$R-\eta_1$ is the distance from the LEO to the turbulence patch.

GPS-COSMIC Occultation Geometry for Air France AF-447 Accident



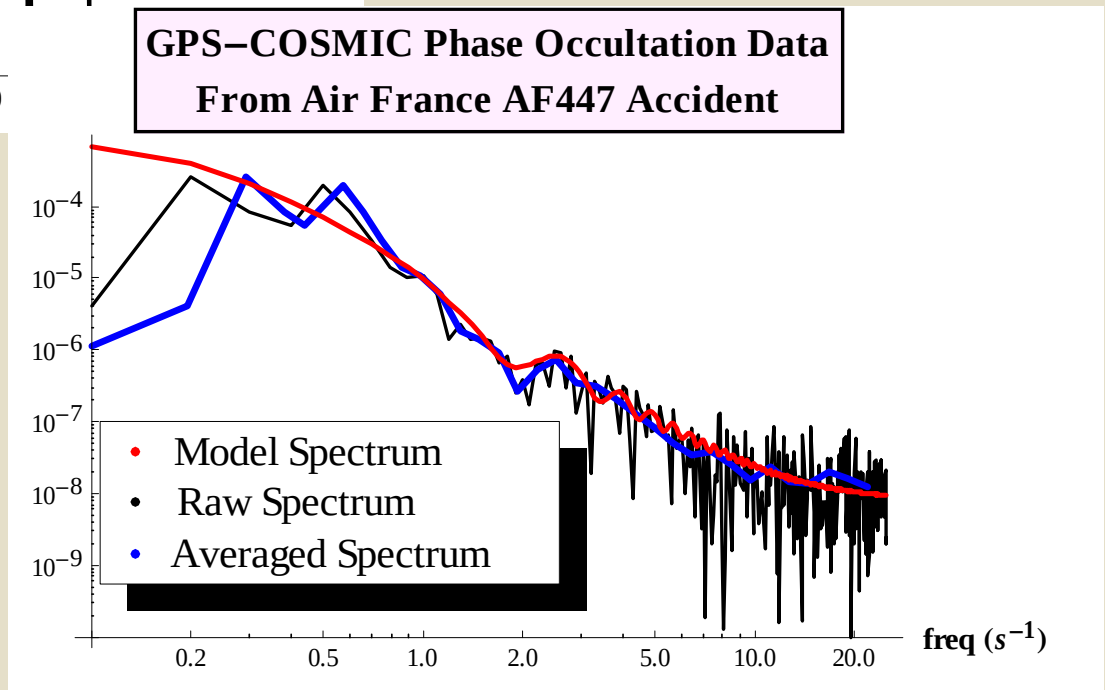
NCAR

GPS Turbulence: Measurement vs. Theory

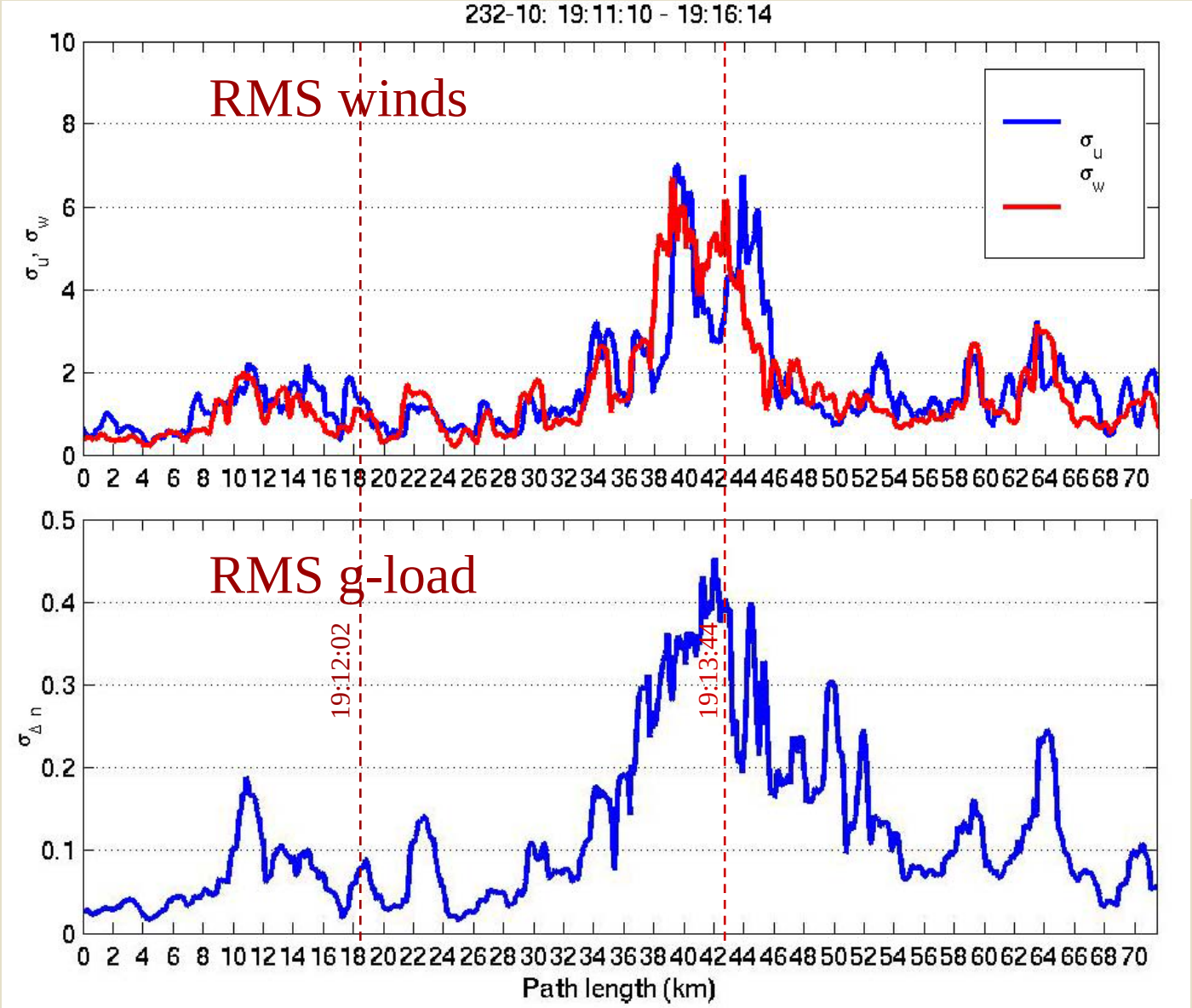


Amplitude

Phase

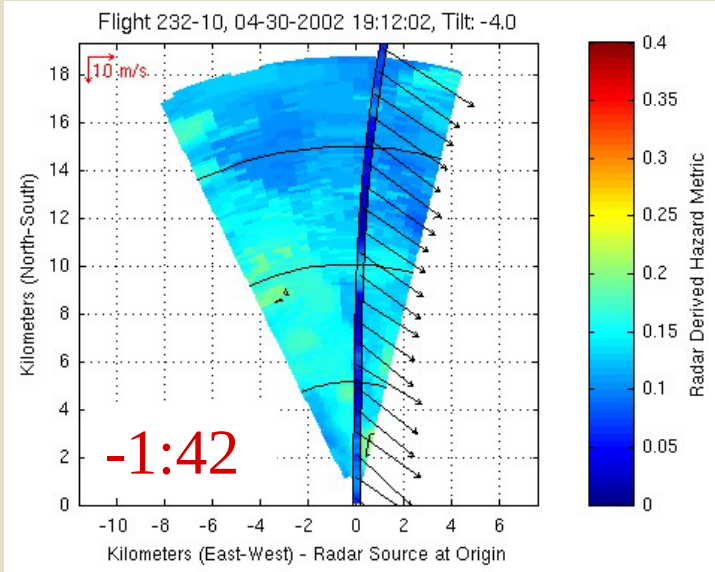


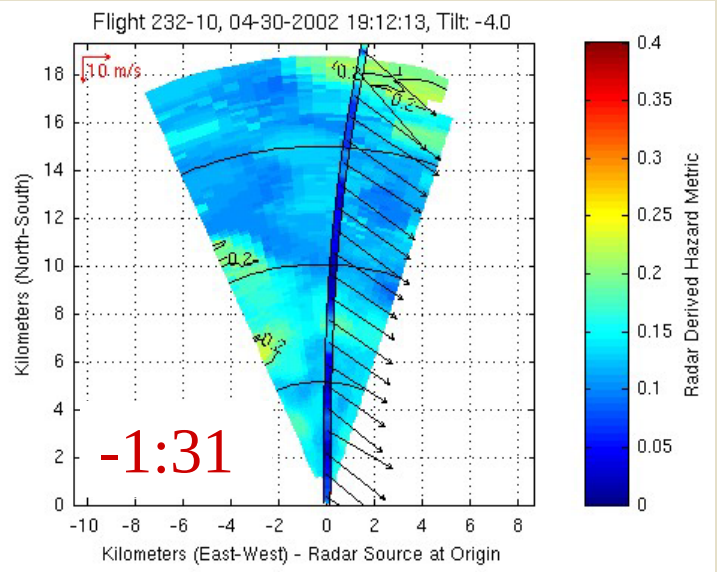
NASA Airborne Radar Detection of Turbulence Program

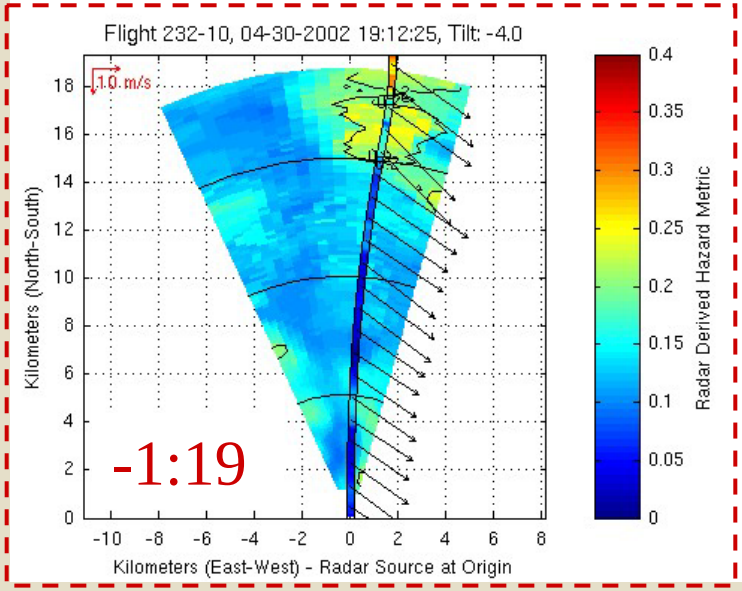


From NASA B-757 Aircraft

Event 232-10 (19:12:02, 19:12:13, 19:12:25)



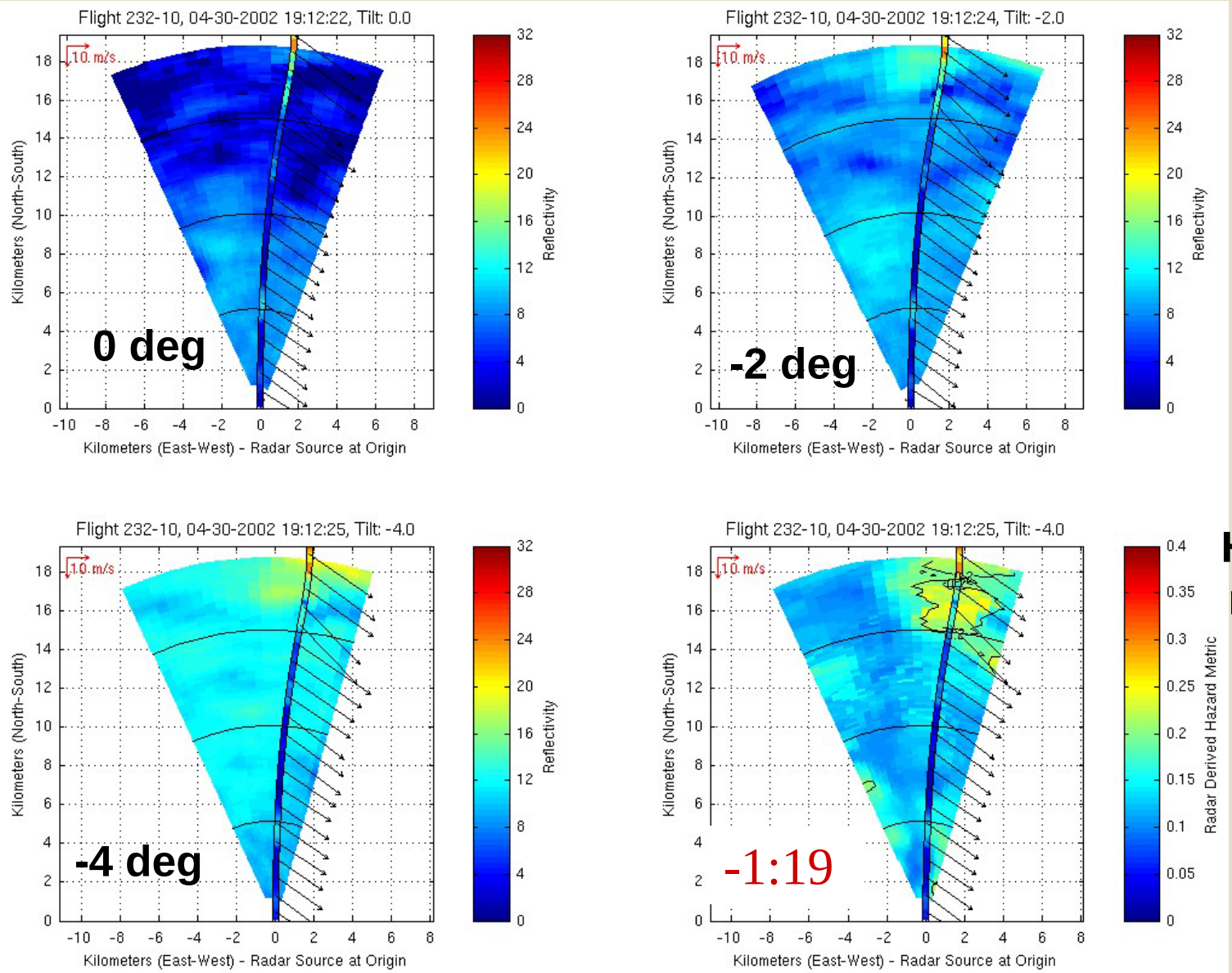




Hazard detected

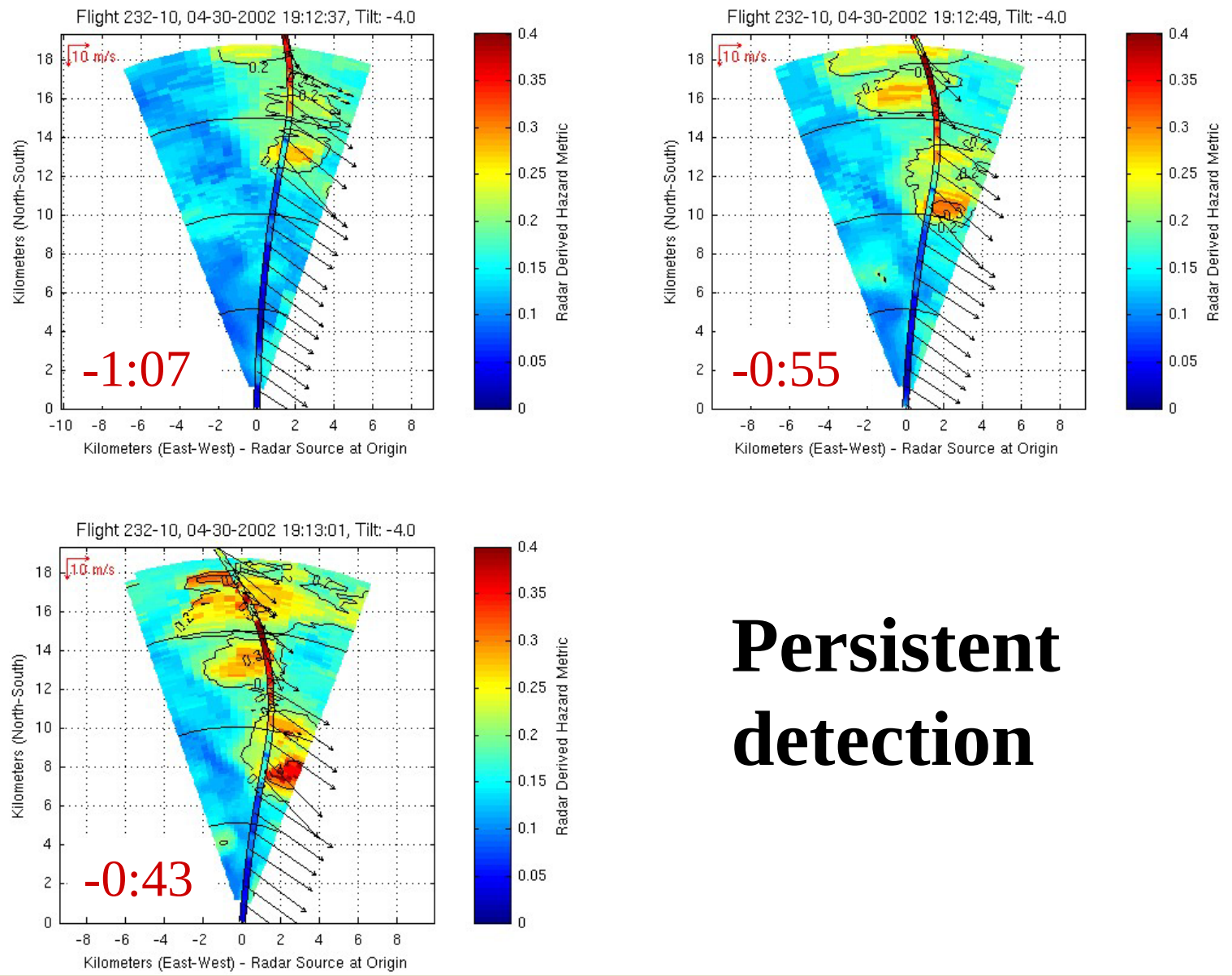
1:19, 18 km to encounter

Event 232-10 (reflectivities at 19:12:25)



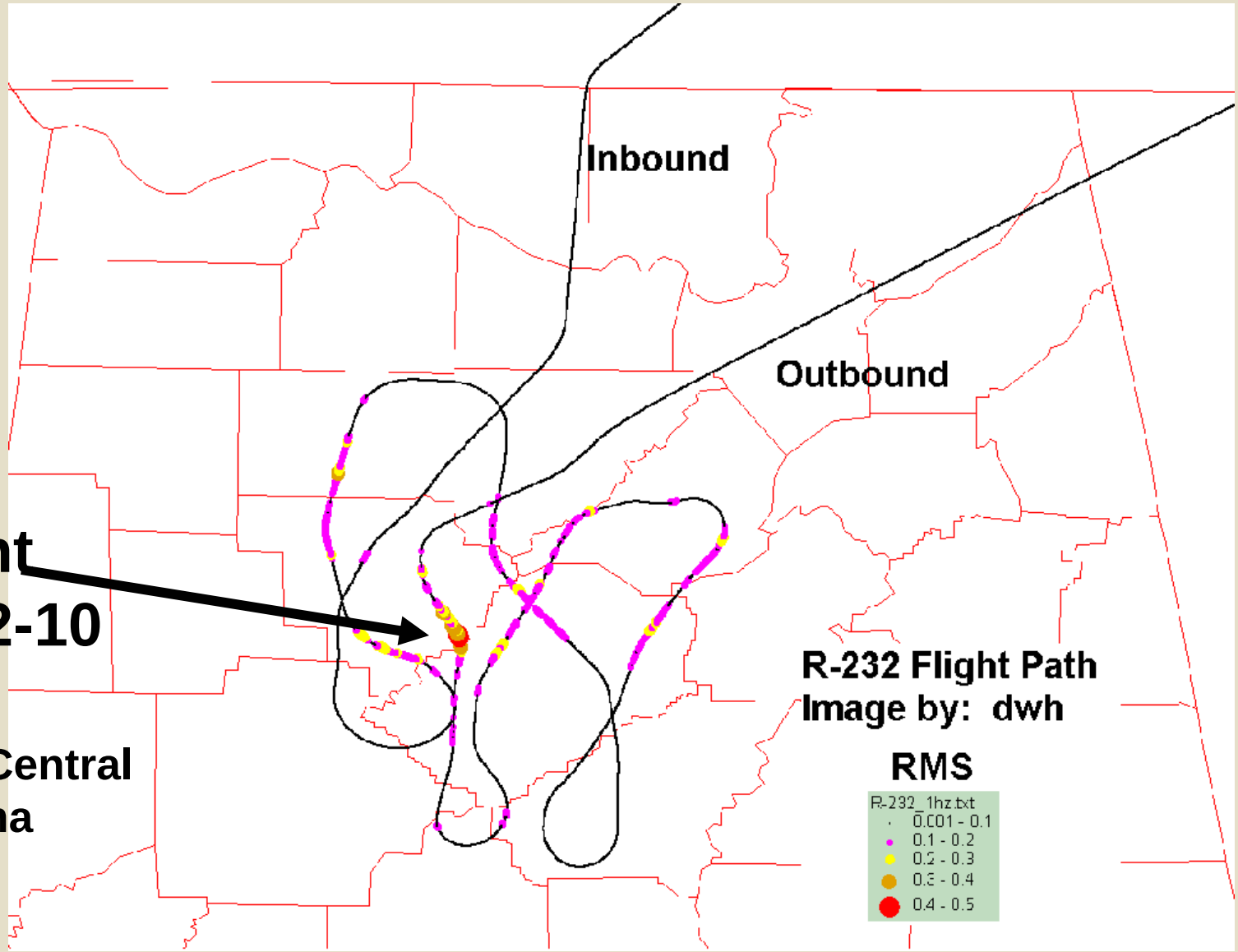
Hazard metric

Event 232-10 (19:12:37, 19:12:49, 19:13:01)



Persistent detection

Flight Track for NASA flight R232

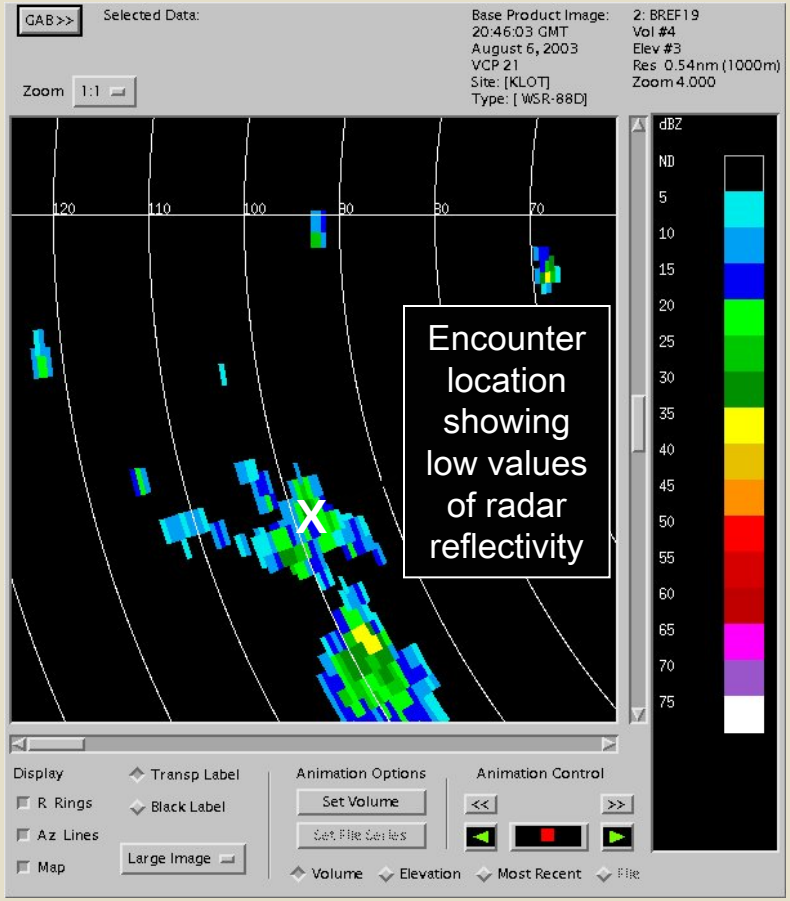


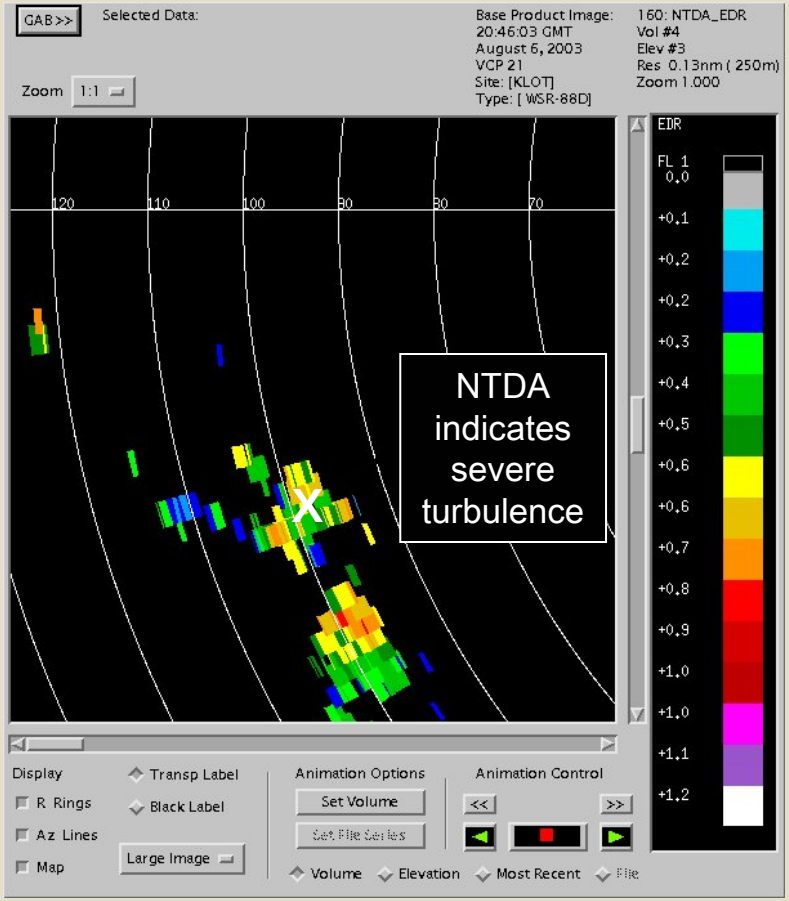
Event R232-10

North-Central Alabama

Turbulence detection via WSR-88D/NTDA: Severe encounter at FL 310

- Vertical acceleration from -0.9 g to +2.3 g in about 3 seconds
- 43 minor injuries, two serious; cabin damage
- 8 min. warning could have reduced/eliminated injuries





KPAH reflectivity 8 minutes prior: 15-30 dBZ

NTDA EDR: 0.55-0.65 $m^{2/3}\ s^{-1}$ (severe)

NASA IR Spectrometer Field Test Boulder, Jan. 2008

Wave clouds
in the lee of the mtns

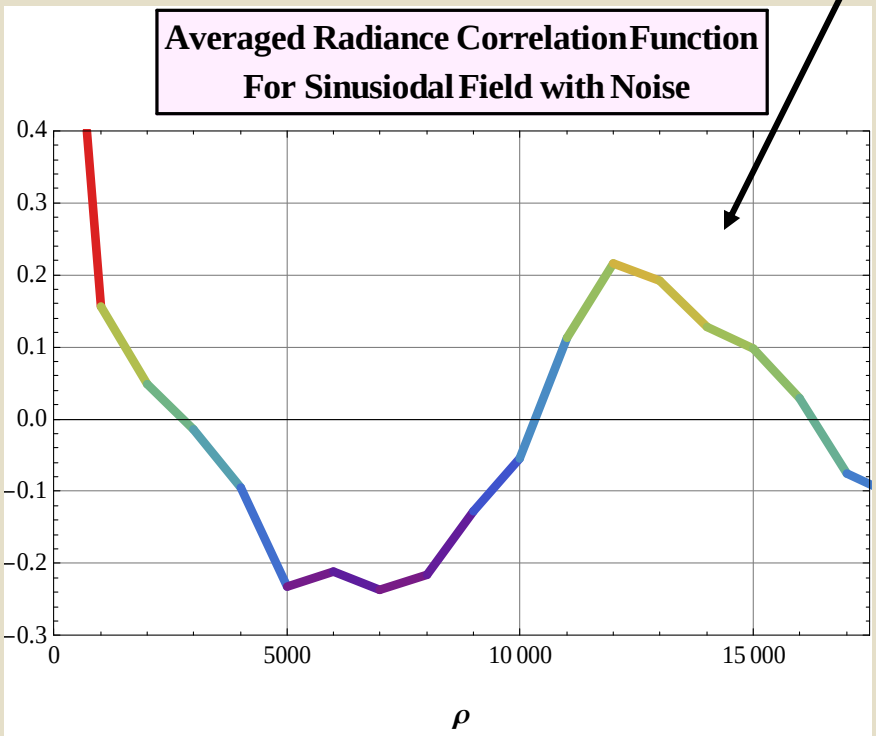
View
out
of
the
trailer

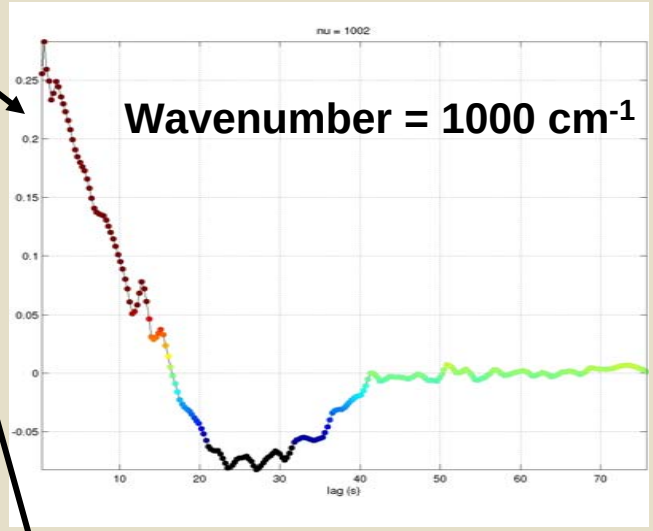
Spectrometer

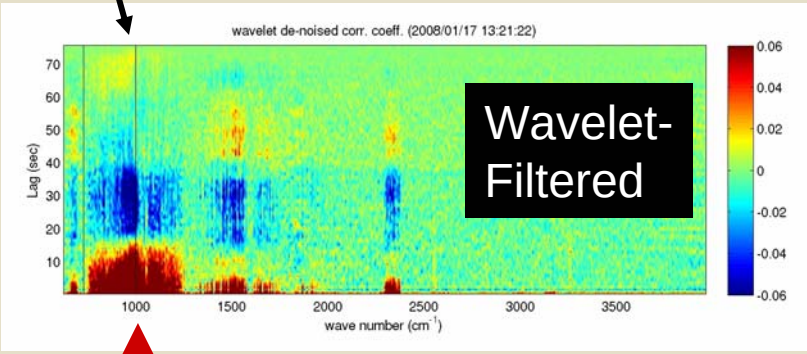
NCAR

Comparison of Field Measurements and Theory

Wave-like Oscillations (12.5 km wavelength)







Theory: Correlation Coefficient for Sinusoidal Temperature Field, as a Function of Temporal Lag.

Measurement: Correlation Coefficient. Vertical Axes is Temporal Lag, Horizontal is wavenumber.

Gap Analysis

- Turbulence can be such a variable (space & time) phenomena; hence, there will always be a measurement gap for tactical aviation purposes.
- This is due to:
  - Lack of all-weather sensors. GPS is, but radars (precip), lidars (aerosols), etc. are not.
  - Economics of getting sensors onboard aircraft.
  - Limited range for many sensors.

NCAR

Gap Analysis, cont'd.

- So, what can we do in the near-term?
  - Downlink turbulence detections from airborne Doppler radars.
  - Apply WSR-88D algorithm (NTDA) to TDWR radars.
  - Continue GPS (esp. airborne application) & IR studies.
  - More/better use of satellite information (esp. for future deployments).
  - Incentives for manufacturers/airlines to improve/employ technologies (economy of scale)?

NCAR